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Application No.	2001/0827
Date of Filing	13 September 2001
Applicant	PLASMA IRELAND LIMITED, a company registered in Ireland with number 193376 of 22 Summerhill North, Cork.

Dated this 30 day of October 2003.

An officer authorised by the
Controller of Patents, Designs and Trademarks.

FORM NO. 1

2001/0827.

REQUEST FOR THE GRANT OF A PATENT

PATENTS ACT, 1992

The Applicant(s) named herein hereby request(s)

[✓] the grant of a patent under Part II of the Act

[ ] the grant of a short-term patent under Part III of the Act

on the basis of the information furnished hereunder.

1. Applicant(s)

Name PLASMA IRELAND LIMITED

Address 22 Summerhill North, Cork

Description/Nationality

A company registered in Ireland with number 193376

2. Title of Invention

An improved method of increasing the irradiance of a target area and its uniformity by a Light Emitting Diode-based Illuminator.

3. Declaration of Priority on basis of previously filed application(s) for same invention (Sections 25 & 26)

Previous filing date	Country in or for which filed	Filing No.

4. Identification of Inventor(s)

Name(s) of person(s) believed by Applicant(s) to be the inventor(s)

JULES BRADDELL

KIERAN KAVANAGH

TONY HERBERT

Address

all of 22 Summerhill North, Cork

CONTINUED OVER

5. Statement of right to be granted a patent (Section 17 (2) (b))

By virtue of the Inventors all being employees of the Applicant and under their contracts of employment

6. Items accompanying this Request - tick as appropriate

(i) [✓] Prescribed filing fee (£ 100 - 00

(ii) [ ] Specification containing a description and claims

[✓] Specification containing a description only

[✓] Drawings referred to in description or claims

(iii) [ ] An abstract

(iv) [ ] Copy of previous application(s) whose priority is claimed

(v) [ ] Translation of previous application whose priority is claimed

(vi) [ ] Authorisation of Agent (this may be given at 8 below if this Request is signed by the Applicant(s))

7. Divisional Application(s)

The following information is applicable to the present application which is made under Section 24 -

Earlier Application No: ....

Filing Date: ....

8. Agent

The following is authorised to act as agent in all proceedings connected with the obtaining of a patent to which this request relates and in relation to any patent granted -

Name **Address**

Oifig na bPaitinní
FAIGHTE
£100 cheque.
13 SEP 2001
98837.

9. Address for Service (if different from that at 8)

Plasma Ireland Ltd.,
22 Summerhill North,
CORK

Signed Name(s): TONY HERBERT

Tony Herbert

Capacity (if applicant is a body corporate):
Managing Director & Company Secretary

Date 12th September 2001

An improved method of increasing th irradiance of a target area and its uniformity by a Light Emitting Diode-based Illuminator

Illuminators based on Light Emitting Diodes (LEDs) are widely used for machine vision, sensing, alignment, medical, sorting, ambient lighting and other applications. For many illuminators such as line sources, backlights and ring lights, certain attributes are critical to performance:

- highly directional light output to focus the light on the required target area giving high irradiance (defined as the radiant power per unit surface area, W/m^2) of the target area;
- efficient extraction of the light emitted by the LED and its transmission from the illuminator, i.e. small internal losses of light, giving high irradiance of the target area;
- highly uniform light output so that the target area is evenly lit.

Such attributes are not readily available from LEDs. These are grain sized parallelepipeds (called die) of semiconductor material which emit light when an electric current is passed through the device. The light emitted from an LED die is highly non-directional, being quasi-isotropic, and is spatially non-uniform in radiant intensity (defined as the radiant flux emitted per space angle, W/sr).

Conventionally, to address the problems of non-directionality and non-uniformity and to achieve the above mentioned desired attributes, the following methods have been used to build LED-based illuminators:

1. LED die are packaged by mounting each die inside a tiny metal reflecting cup, the whole then being surrounded by an encapsulating epoxy or plastic in the shape of a domed or other geometry lens. Degrees of directionality and uniformity of light output are achieved by the operation of the shaped reflector and by the lensing effect. A disadvantage is that the space occupied by a packaged LED is much larger than the space occupied by a LED die so that packing density is greatly reduced in the case of arrays of packaged LEDs. To produce an illuminator, one or two dimensional arrays of packaged LEDs are mounted onto circuit boards in rows and/or columns, in circles or other geometries, commonly called stuffing. This method suffers from disadvantages:
    - the low packing density of the packaged LEDs results in low output power and, hence, low irradiance at the target;
    - the packaged LEDs cannot be mounted on the circuit board in a sufficiently controlled manner to ensure that the optical axis of each LED is identically aligned in the desired direction. Thus, light distribution and uniformity is non-optimum and there is generally a divergence of up to about 20° between the mechanical axis of the illuminator and its optical axis, again producing non-optimum irradiance at the target;
    - Heavy diffusers over the top of the packaged LED arrays are required to blur out the contributions of the individual LEDs and give some level of uniformity. Such diffusers cause loss of emitted light due to internal reflection and, thus, reduce the overall efficiency of the illuminator;

- Design flexibility is limited due to the need to produce a new circuit board for each design;
- Thermal management is difficult due to the insulating properties of the circuit board and the LED die encapsulation. Excessive heat reduces efficiency and LED lifetime;
- Large footprint and volume. This is a serious issue for many, if not most applications, due to space constraints in fitting illuminators into many systems.

2. The Evenlight® process is a variation on 1 above in which each individual packaged LED in the illuminator array is matched for power output and aligned by hand at assembly using a target system. This results in much improved light uniformity and reduced thickness diffuser. However, the most serious disadvantages of low LED packing density and large size remain with the added problem of labour intensive, high cost manufacture.

3. Chip and wire technology – Here the LEDs are not individually packaged in reflector cup and lens. Instead, the individual die (also called chips) are bonded directly onto a circuit board in arrays. Electrical contact is made using conventional wire bonding to bond pads on the board. The whole board with die is encapsulated in epoxy for protection of the die and bonds and mounted in a metal can. A large scale glass or other lens is then bonded over the entire array. This greatly increases the packing density of the LEDs over the preceding methods, but such density is limited by the critical dimensions available from Printed Circuit Board (PCB) technology which are large relative to Integrated Circuit (IC) technology. This limit on packing density is particularly acute where a multiple wavelength illuminator is required. Such an illuminator requires a multiplicity of metal interconnect tracks for electrical biasing and driving of the different LEDs needed, one type for each wavelength. The pattern size limitations of PCB technology mean that the LEDs have to be more widely spaced apart in multiple wavelength illuminators thus reducing packing density and increasing size and bulk. Manufacturing costs are increased by the need to make a separate lens and attach it to the illuminator. Lack of a back reflector behind each die results in loss of output light due to internal absorbtion within the illuminator greatly reducing target irradiance. Light output is further reduced by internal reflection at the epoxy/lens interface.

The invention relates to a method or process for the building of LED-based illuminators, which give higher target irradiance and greater spatial uniformity in radiant intensity over the target area than conventional LED-based illuminators. The method is based upon:

1. The use of a reflective carrier (herein called "Carrier") onto which the LED die are directly mounted and which is patterned using conventional IC techniques, such as photolithography and metal etching, to provide the electrical circuitry needed to drive the LEDs.
2. The use of a focussing lens fabricated from and monolithic with the LEDs' protective encapsulation.
3. The use of a front surface light diffuser transmitter placed in close optical contact over the array of LED die.

4. The use of a can onto the base of which the Carrier with its cargo of LED die is mounted and which is designed so that the internal sides of the can form an integral part of the reflective optics of the system.
5. The use of the outer enclosure of the illuminator as a heat sink by thermal bonding to the can.

According to the invention there is provided a method for the manufacture of LED-based illuminators which comprises the following steps:

1. A material is selected to act as a Carrier for the LED die or monolithic arrays of LED die. Such material will be electrically insulating or semiconducting but will have high thermal conductivity and will be compatible with microelectronic processing techniques and the fabrication of ICs. Possible examples of such material are Silicon, diamond, diamond-like-carbon, Gallium Arsenide, Indium Phosphide, sapphire and glass. Such material typically would come in sheet or wafer form and should have a highly polished face suitable for specular reflection of light.

2. Electronic circuitry is defined and fabricated onto the Carrier material by conventional microelectronic IC fabrication techniques such as photolithography, metallisation, ion implantation, etching, deposition and isolation saw cutting. Such circuitry, especially metal tracks for electrically biasing the LEDs, can be defined down to 1 micrometre critical dimension or better using such IC fabrication techniques, much higher resolution than with PCB technology. Such circuitry includes bond pads onto which LED die or arrays may be placed or to which bond wires from such die or arrays may connect. Such circuitry may include one or more metal interconnect tracks corresponding to each LED die or to more than one LED die, generally all of the same type in a multiple wavelength system, which track or tracks may include one or more metal contact or bonding pads to enable electrical contact to be made by conventional microelectronic bonding techniques between the LED or LEDs and the pins of conventional IC packages or other enclosures or external leads. Such circuitry may include logic, driving, control, active or passive electronic functionality and may be on multiple levels.

3. Most of the surface of the Carrier is metal coated by conventional thin film deposition techniques to create a highly specular reflecting surface on the Carrier.

4. A single unit thus produced is termed herein a Carrier. Using conventional microelectronic fabrication techniques, many Carriers can be fabricated out of a single sheet or wafer of material. The sheet or wafer is divided into separate individual Carriers, for example by dice-sawing or scribing.

5. Carriers are placed onto a flat metal or other baseplate or into an enclosure, can or package. This may be, for example, a customised metal can with, of course, one side open or a conventional IC package. The baseplate, enclosure, can or package is customised to the geometry of the particular illuminator required for the application, for example a line, a plate, a disc or a ring. If more than one Carrier is so mounted, the Carriers are placed so that the LEDs to be mounted on the Carriers will form the geometrical array suitable for the application. Each Carrier is mechanically bonded to the baseplate, enclosure, can or package, for example by epoxy. If a can is used, the geometry or shape of its interior should

be an integral part of the reflective optics of the system so that the internal sides of the can are sloped, curved or graded to ensure that light emissions from the LED die being non-normal to the Carrier surface, i.e. not parallel to the main axis through the can cross-section, such as side or back emissions, are subject to specular reflection from the can sides so as emerge from the open side of the can close to normal to the carrier surface, i.e. close to parallel to the main axis through the can cross-section. The internal side surfaces of the can are polished and/or metallised, for example with silver, so as to enhance their reflectivity.

6. Individual LED die or monolithic arrays of LED die are mounted by conventional die attach processes, for example using conducting silver epoxy, onto bond pads (herein called die pads) on each Carrier in arrays, such as linear, 2-dimensional and circular, customised to produce the required illuminator. Each die has two metal contacts, called the p-contact and the n-contact. One contact is on one face of the die, the top face, while the other contact is on the opposing face of the die, the base face. Each die is placed onto its die pad so that a selected contact, either p or n, touches the die pad either directly or through the epoxy or glue to form an electrically conducting path from the die pad into the LED die.

7. To complete the electrical circuitry for driving the LEDs, conventional wire bonding techniques, such as gold ball bonding or aluminium wedge bonding, are used to connect, firstly, the die pad holding the LED die and, secondly, the metal LED contact, either p or n, now on the top face of the die and not bonded to a pad, to bond pads or metal interconnect tracks on the Carrier. Each LED will, therefore, require two wire bonds, one for the p-contact and one for the n-contact, going to different bond pads or interconnect tracks to allow an electrical voltage or bias to be applied across the LED through such pads or tracks. Such bond pads or metal interconnect tracks are themselves electrically connected by wire bonding or soldering to the pins of the enclosure, can or package or to external leads anchored to but electrically isolated from the baseplate, can or enclosure.

8. A front surface diffuser transmitter in the form of a flat plate of material which is transparent to the light emitted by the LEDs but which acts so as to scatter the incident light is now placed over the top of the LED array parallel to the surface of the Carrier. This is done by covering the Carrier and its cargo of LEDs with an epoxy which has a refractive index on curing close to or matching that of the diffuser and then placing the diffuser on the uncured epoxy. The epoxy is cured hard to secure the diffuser permanently in place.

9. Either as an alternative or in addition to step 8 ante, a lens can now be built onto the unit. The unit of LEDs, Carriers and baseplate, can, enclosure or package and, optionally, diffuser is now inverted, so that the LEDs and Carriers face down, and is placed into a mould resting on slots cut into the two ends of the mould. The mould is made, typically, from teflon which may be sprayed with silicone or other release fluid. The cross-section of the mould is shaped to form the lens suitable for the illuminator. The electrical leads or pins connecting the illuminator externally are outside the mould. Epoxy, resin, plastic, silicone or other material is poured into the mould to a height that covers the Carriers and LEDs. The epoxy, etc. is cured to a solid by oven or hotplate bake or by Ultra Violet illumination or other process. After curing, the mould is removed to reveal the completed illuminator with integrated lens.

10. For improved thermal management of the illuminator, the Carrier with its cargo of LEDs should be placed on the base of a metal can according to step 5 ante. In turn, the metal can is thermally bonded to a metal enclosure, which contains the entire illuminator, together with, if required, PCB and/or other electronic drive and/or control circuitry. The metal enclosure acts as a heat sink so that heat from the LED die is conducted with reasonable efficiency to the Carrier, thence to the metal can and, finally, to the metal enclosure.

The method and process carried out in accordance with the invention has the following advantages:

1. Very high packing density of LEDs is achieved producing high light output power and high irradiance at the target;
2. Due to the use of IC patterning techniques, multiple wavelength illuminators can be built with high LED packing density even when many different type LEDs are required;
3. Efficiency (defined as: light power output in Watts / electrical power input in Watts) of the system is relatively high due to collection of the back and side emissions of light from the LED die by specular reflection from the surface of the Carrier and the interior surfaces of the shaped can and their redirection towards the front of the system;
4. Efficiency of the system with the front surface diffuser is relatively high due to efficient coupling of the light from the LED die into the diffuser due to the effect of the scatter providing multiple critical angles for the light to escape as opposed to a non-diffusing surface with only a single critical angle;
5. Efficiency of the system with the integral lens is relatively high due to efficient coupling of the light from the LED die into the lens with minimal losses from internal reflections;
6. Very robust mechanical construction;
7. Small size and footprint;
8. Precise alignment between the optical and mechanical axes;
9. Highly spatially uniform light output without the need for external, i.e. not directly optically coupled to the LED die, or additional diffusers;
10. Efficient cooling due to the proximity of the LED die to the high thermal conductivity Carrier and can, enclosure, baseplate or package and the presence of a heat sink in the illuminator enclosure via its bond to the can;
11. Manufacturing is relatively simple and low cost and can be easily automated.
12. Electronic circuitry can be fabricated on the Carrier and thus integrated with the LED or LED array within the illuminator

The invention will be more clearly understood from the following description of some of the embodiments thereof given by way of example only with reference to the accompanying drawings.

One embodiment of the invention defines a single wavelength line illuminator. Figure 1 is a plan view of a Carrier 1. The Carrier 1 is fabricated from a rectangle of silicon wafer metallised with gold, silver or other metal pads 2 approximately 1 micrometre in thickness. The pads 2 constitute the die pads and bond pads mentioned above. The width of the pads 2 is chosen so as to allow easy bonding of LED die or monolithic arrays of die to the die pad or to allow easy wire bonding. The length of the pads 2 is determined by the number of wire bonds it is to receive or by the number of die to be bonded to a single pad 2 which, in turn, is determined by the values of voltage to be

applied to and current to flow through each die. Figure 2 is a plan view of a Carrier 1 mounted onto an aluminium baseplate 3 with LED die 4 bonded to die pads 2 and two external leads 5 soldered to bond pads 2. Figure 3 is the same plan view as Figure 2 but with wire bonds 6 completing the electrical connections between all LED die 4 and the external leads 5. This unit is now inverted and placed into a mould as described above. The external leads 5 protrude outside the mould. Epoxy, such as E501 supplied by Epotecny of Levallois-Perret, France, is poured into the mould to a level that just covers the die and Carrier. The unit is oven baked to solidify the epoxy and the mould is then removed to reveal the completed illuminator.

Another embodiment of the invention defines a three wavelength line illuminator. Figure 4 is a plan view of a Carrier 7. The Carrier 7 is fabricated from a rectangle of silicon wafer metallised with gold, silver or other metal pads 2 approximately 1 micrometre in thickness. The pads 2 constitute the die pads and bond pads mentioned above. The width of the pads 2 is chosen so as to allow easy bonding of LED die or monolithic arrays of die to the die pad or to allow easy wire bonding. The length of the pads 2 is determined by the number of wire bonds it is to receive or by the number of die to be bonded to a single pad 2 which, in turn, is determined by the values of voltage to be applied to and current to flow through each die. Figure 5 is a plan view of a Carrier 7 mounted onto an aluminium baseplate 8 with three types of LED die 9 (for example outputting red light), 10 (for example outputting green light) and 11 (for example outputting blue light) bonded to die pads 2 and six external leads 12 (positive electrical bias to the red LEDs 9), 13 (positive electrical bias to the green LEDs 10), 14 (positive electrical bias to the blue LEDs 11), 15 (electrical ground to the red LEDs 9), 16 (electrical ground to the green LEDs 10) and 17 (electrical ground to the blue LEDs 11) soldered to connector blocks 18. The connector blocks 18 are rectangles of insulating sheet, for example silicon wafer, glued, for example with non-conductive epoxy, to the baseplate 8 with the top surface of the connector block 18 metallised, for example with 1 micrometre of gold. The bared end of each of the external leads 12, 13, 14, 15, 16 and 17 is soldered to one only connector block 18. Figure 6 is the same plan view as Figure 5 but with wire bonds 19 completing the electrical connections between all LED die 9, 10 and 11 and the external leads 12, 13, 14, 15, 16 and 17. This unit is now inverted and placed into a mould as described above. The external leads 12, 13, 14, 15, 16 and 17 protrude outside the mould. Epoxy, such as E501 supplied by Epotecny of Levallois-Perret, France, is poured into the mould to a level that just covers the die and Carrier. The unit is oven baked to solidify the epoxy and the mould is then removed to reveal the completed illuminator.

In one embodiment of the invention, the mould has a circular cross-section to produce a lens that either focusses or diverges the emitted light in a line.

In another embodiment, the mould has a Fresnel-like cross-section to produce a lens that either focusses or diverges the emitted light in a line.

In another embodiment, the mould has a rectangular cross-section.

In another embodiment of the invention, the mould has an elliptical or non-circular cross section in order to focus the light the into a line with no spherical abberations. In this case the distance of the top of lens to the LEDs is greater than the focal length.

In another embodiment of the invention, the mould has an elliptical or non-circular cross section in order to diverge the light in a line with no spherical abberations. In this case the distance of the top of lens to the LEDs is less than or equal to the focal length. The degree of divergence can be controlled by adjusting the distance between the top of the lens and LEDs.

In another embodiment of the invention, the Carrier is placed on the base of a metal can shaped as shown in cross-section in Figure 8. The sidewalls of the can are angled so as to reflect side emissions of light from the LED die and direct the light out of the can in a direction approximately parallel to the main axis of the can cross-section, i.e. normal or nearly normal to the first surface of the front diffuser or lens. The light so-presented to the front diffuser or lens will not be reflected back by internal reflection at interfaces within the system, such as the diffuser/air or lens/air boundary, thus increasing overall system efficiency. Figure 7 shows a cross-section of the complete illuminator based around such can including external contact pins, a PCB, a silicon Carrier, lens and outer enclosure.

In other embodiments of the invention, the can interior has multiple angled, circular, elliptical or non-circular curved cross-sections.

Many variations on the specific embodiments of the invention described will be readily apparent and accordingly the invention is not limited to the embodiments hereinbefore described which may be varied in both usage and detail.

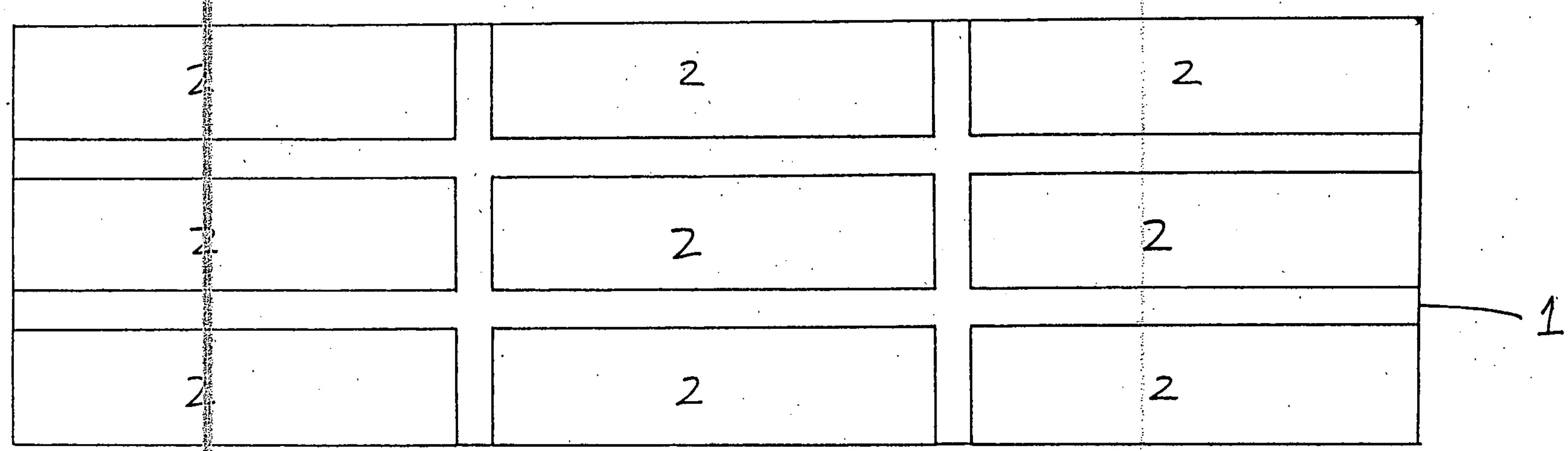


FIGURE 1

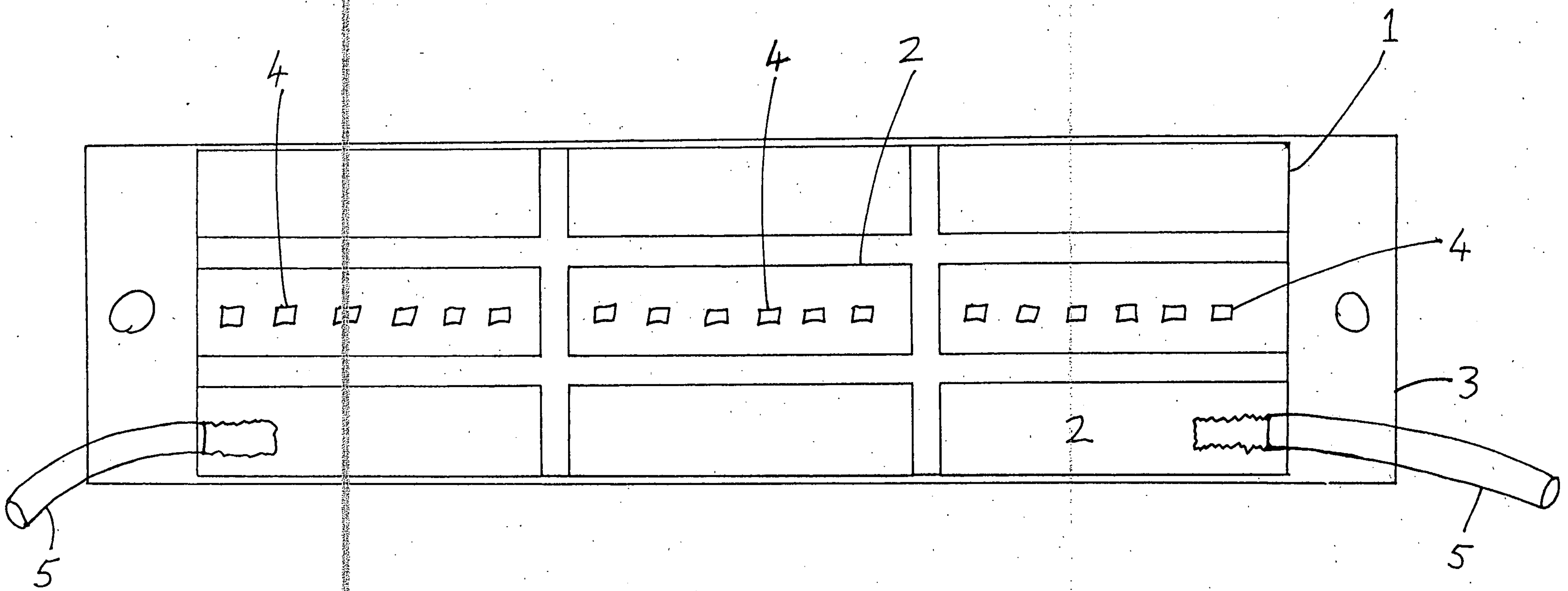


FIGURE 2

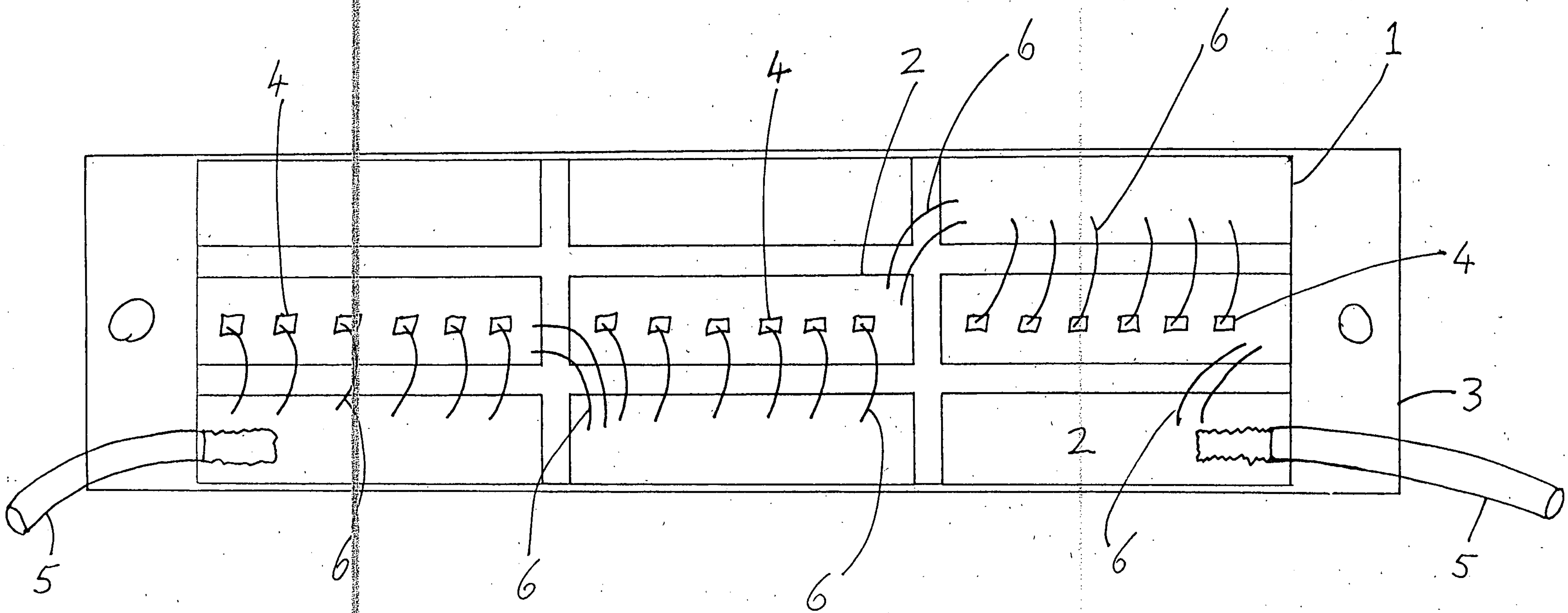


FIGURE 3

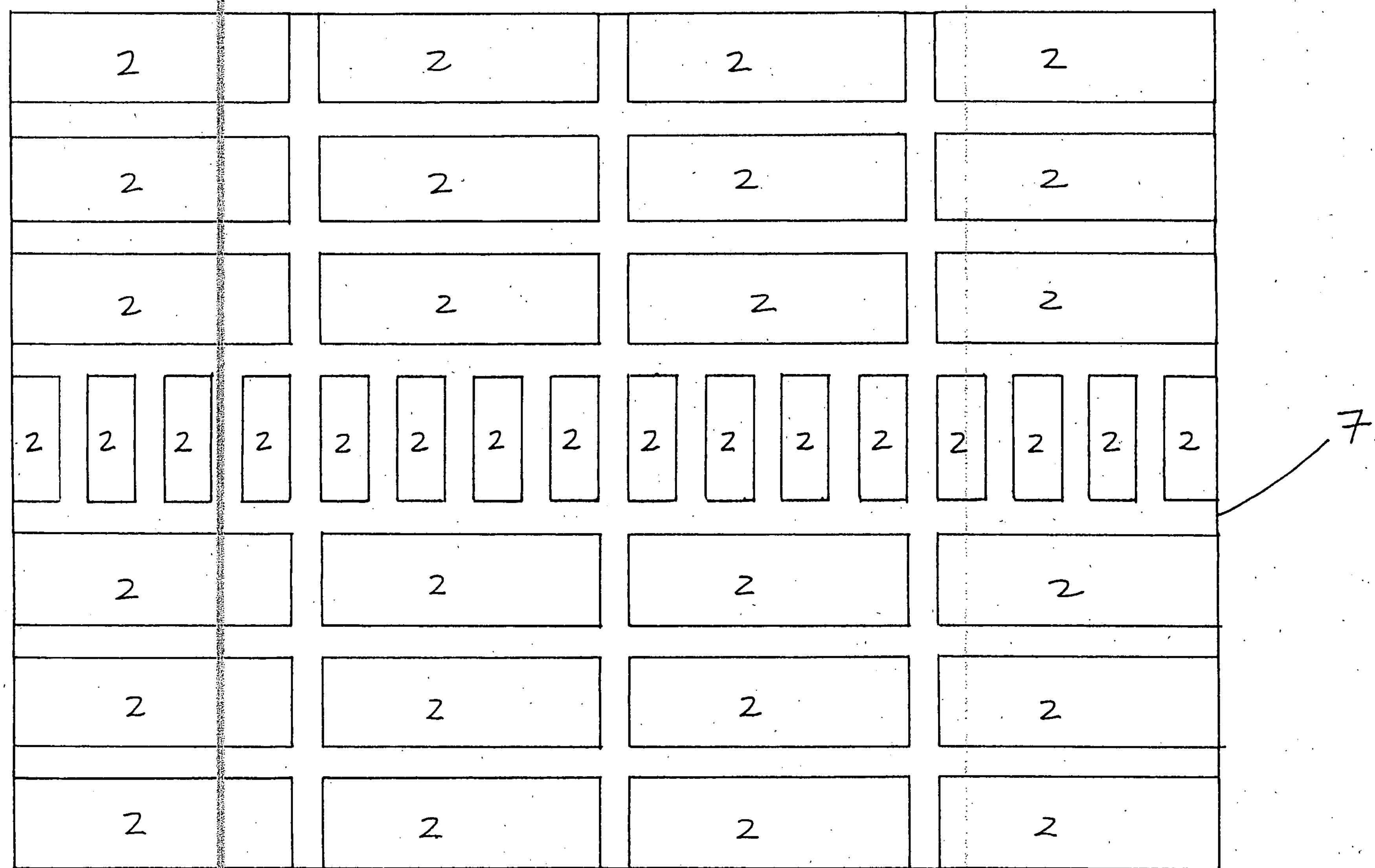


FIGURE 4

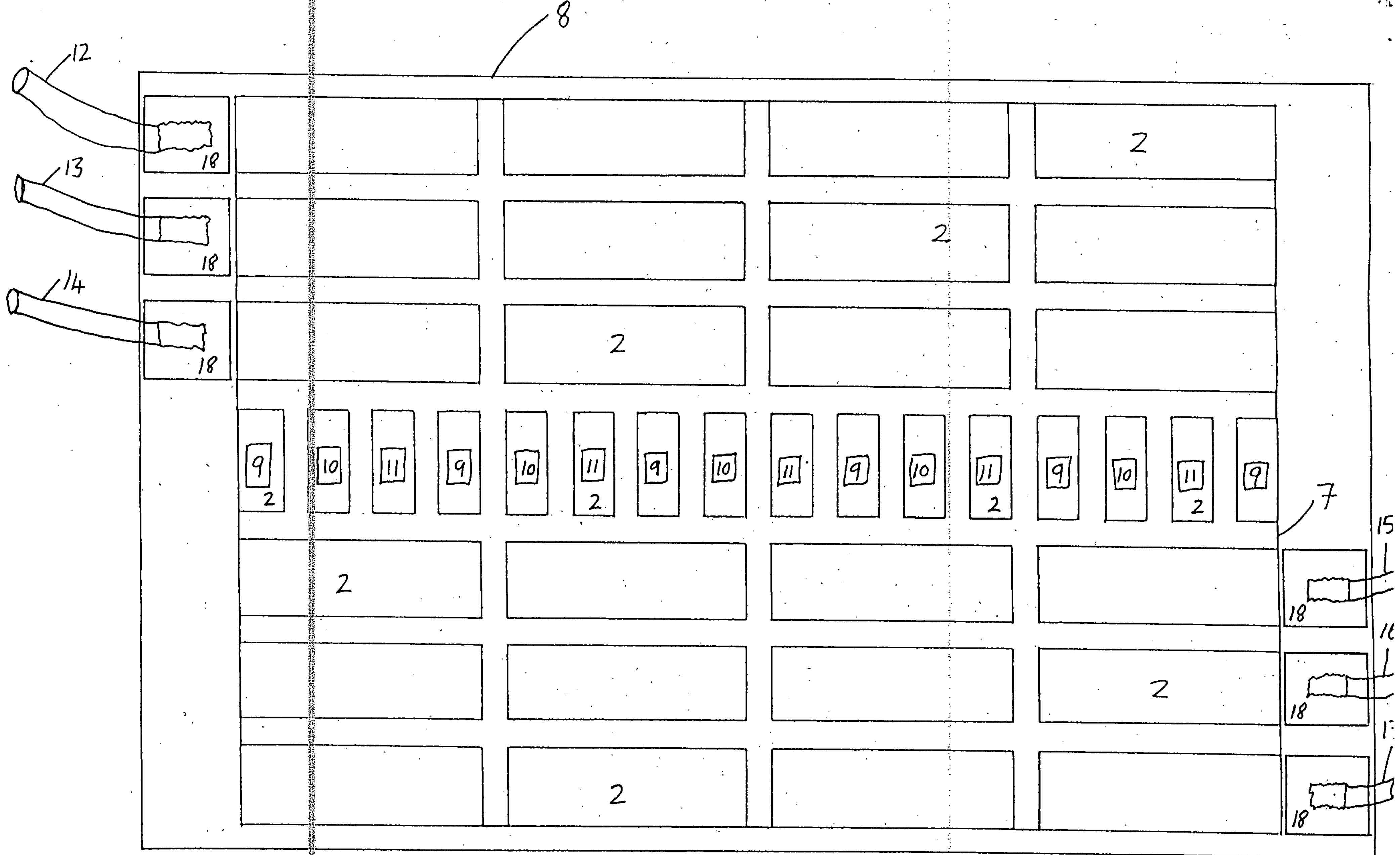


FIGURE 5

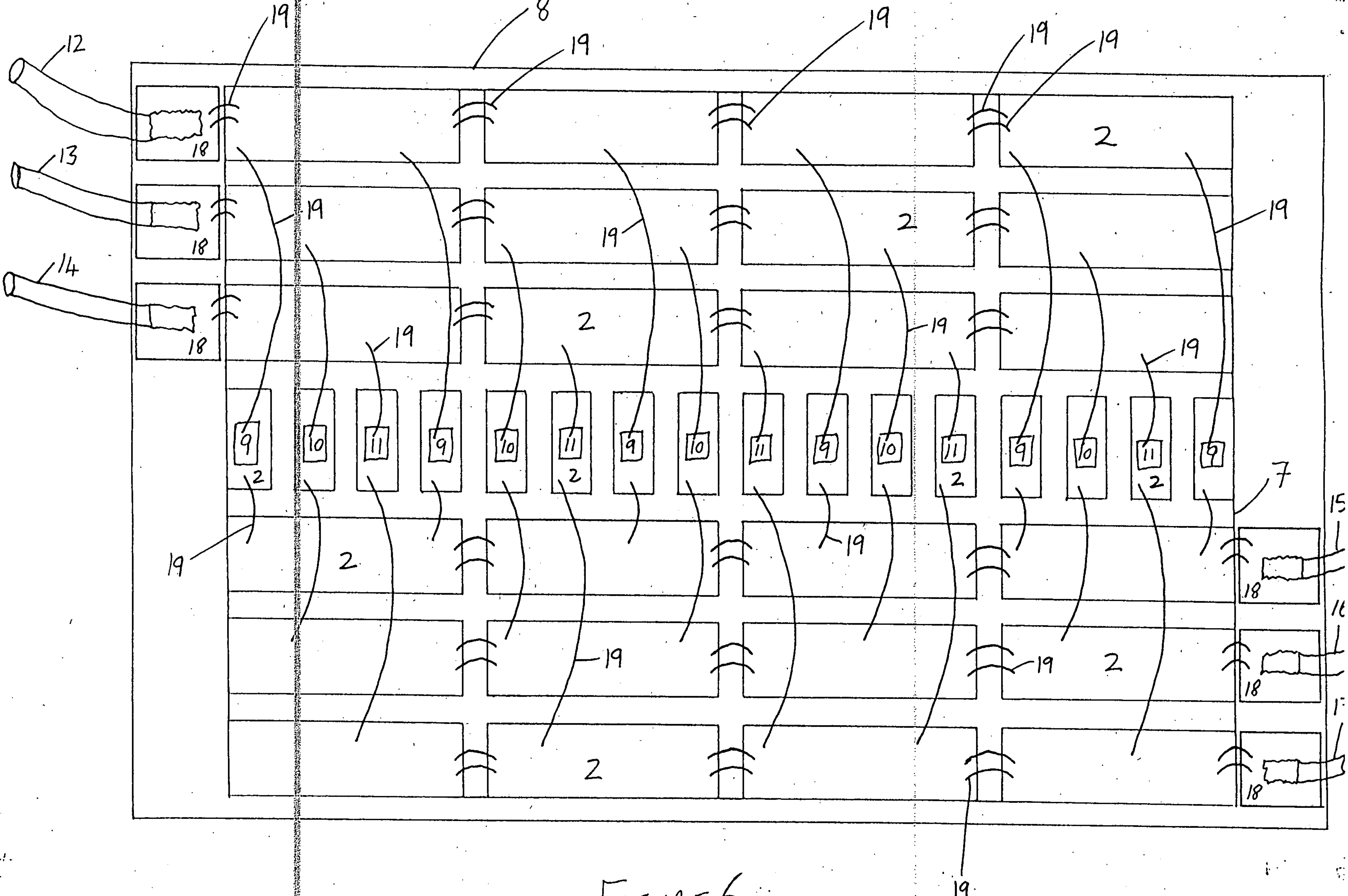


FIGURE 6

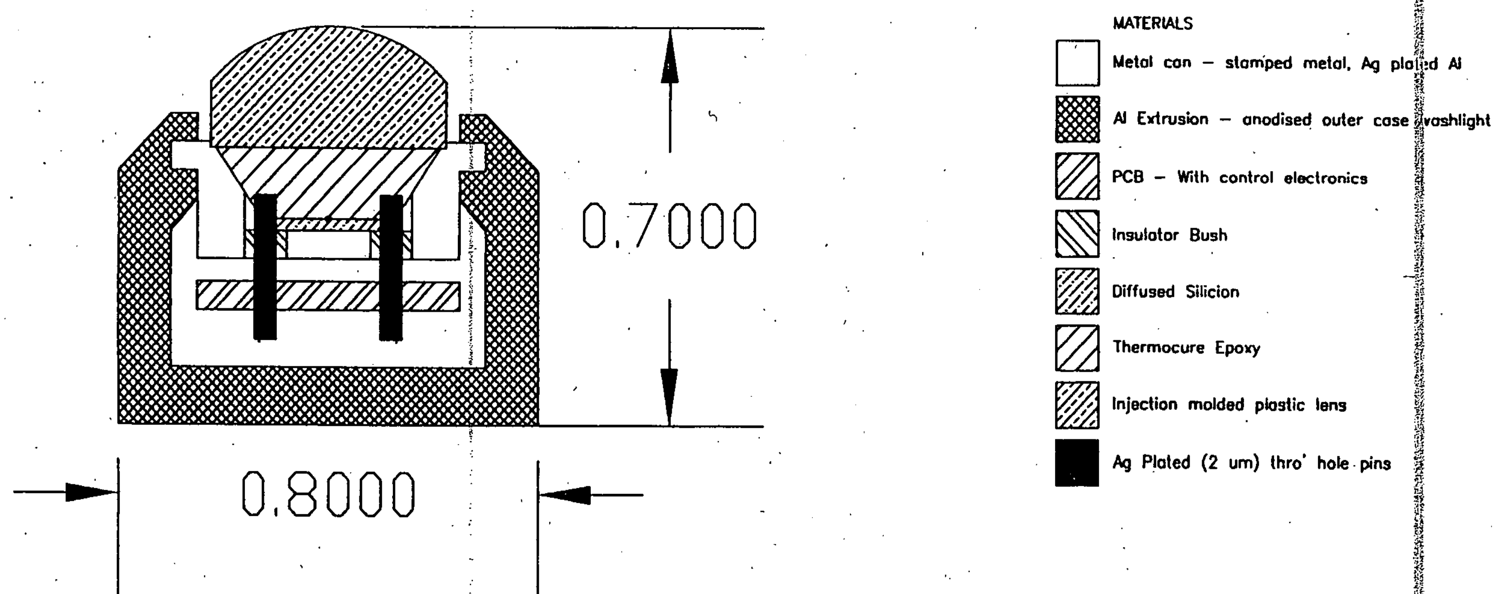
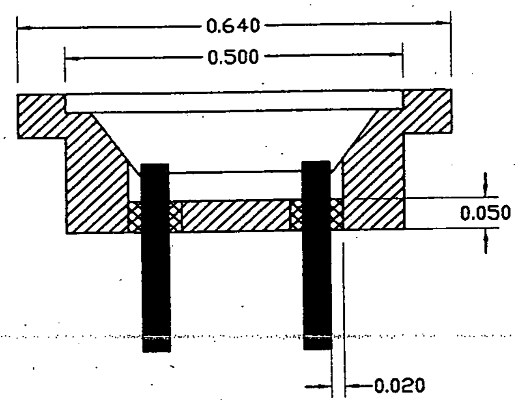


FIGURE 7, LINESOURCE MODULE, INCLUDING LENS AND REFLECTOR PACKAGE
ALL DIMENSIONS IN INCHES, NOT TO SCALE



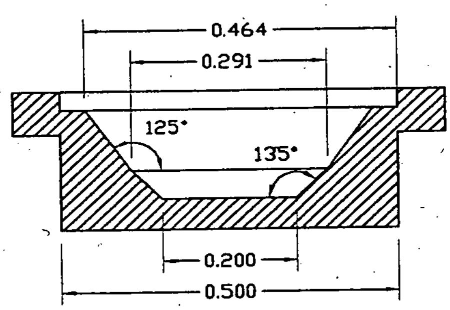
SECTION WITH PINS

1, 2 Materials and Finish

Nickle plate case (2 μm)

Au plate leads (1 μm)

Insulator Bush, must withstand 150C



SECTION WITHOUT PINS

FIGURE 8, METAL CAN PROFILE,
ALL DIMENSIONS INCHES, NOT TO SCALE